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Assessment of potentials of treated wastewater sludge ash as a partial replacement of cement

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***Abstract*—This paper presents the physical, chemical and mineralogical properties sludge ash produced from treated domestic/municipal and industrial wastewaters in Gaborone, Botswana. The findings formed the basis for evaluating the feasibility of using the sludge ash in partial replacement of cement in concretes and mortars. The physical and biological properties revealed the potential of the raw sludge as manure for agricultural purpose. The physical properties of the incinerated sludge at 800°C gave bulk density 810 kg/m^3, pH 7.1, specific gravity 2.45 g/cm^3 and the surface area 6.7 m^2/g which met the standard requirements for cementitious materials. The chemical composition of the sludge ash conducted by x-ray fluorescence (XRF) analysis showed that silica and alumina contents accounted for 50.7% with high content of hematite (>10%). These are reactive oxides which qualified the ash as an active mineral addition in partial replacement of cement. The X-ray diffraction (XRD) analysis of the sludge ash revealed mainly amorphous phase with some peaks of crystalline phases of magnetite, magnesioferrite and different calcium-containing mineralogical compounds due to the presence of calcium oxide contents. It can be concluded that the sludge ash from the Glen Valley treatment can be effectively used in partial replacement of cement in concretes and mortars.**

Keywords—wastewater sludge, blended cement, cementitious materials, concrete, mortar

I. Introduction

The construction industry is a great resources and materials consuming sector with an enormous potential for the use of waste materials generated by its own activities [1]. The use of such waste materials allows decrease the energy consumption, to preserve non-renewable natural resources, and to reduce the high amount of material that goes to landfills. However, in the cement industry, which has always been among the largest CO_2 emission sources, technical, economic and legal challenges still play as remarkable obstacles against the widespread implementation of procedures to help mitigate this situation [2]. Thus, the increase in demand for construction materials in the recent years as a result of development has called for an alternative way to develop or derive construction materials from different sources.

The exorbitant cost of building and construction materials is the greatest challenge confronting housing delivery in low-and-income countries [3]. Unlike the aggregates and water that are locally sourced, the price of cement determines the overall cost of building. Cement is an indispensable material in building and construction works. It is primarily utilized as a binder in the production of sandcrete blocks, concrete and as a stabilizing admixture in soils. In order to ameliorate this problem, alternative materials from a range of widely abundant local materials have been sought to replace the expensive conventional ones, most especially cement. To achieve sustainable development in cement manufacture and building industry, pozzolans such as fly ash, silica fume, rice husk ash and blast furnace slag have been discovered to be viable alternative binders in partial replacement to cement [4, 5]. Other alternatives include recycled crushed glass waste [6-8], recycled aggregate concrete [9] and agricultural wastes such as corn-cob ash [10], rice husk ash [4, 11] cow bone ash, saw dust ash, palm-kernel shell ash and periwinkle shell [12] have been incorporated as pozzolans in partial replacement of regular cement in concrete or mortar structures.

Sludge ash is the by-product produced during the combustion of dewatered sewage sludge in an incinerator. The residues after thermal conversion of sludge are among other things the fly ashes captured from flue gases in electrofilters. These residues are primarily a silty material with some sand-size particles [13, 14]. The character, specific size range and properties of the fly ash are different and depend to a great extent on the type of incineration system [15]. The use of improved construction materials in construction industry has been on increase daily which has led to the identification of its environmental impact and meeting required standards when sewage sludge ashes are used in developing sustainable building material [16]. The most important utilization of sludge ashes in construction industry include partial replacement of cement and/or active additive for cementitious inorganic binders in concrete and mortar. It has also found application as substitute for sand and/or cement in cement stabilized bases.

The purpose of the study was to determine the physical, chemical and mineralogical properties sludge ash produced from a 90 Ml/day capacity central treatment plant which processes domestic, municipal and industrial wastewater in Gaborone, Botswana. The findings formed the basis for evaluating the feasibility of using the sludge ash in partial replacement of cement in concretes and mortars.

II. DESCRIPTION OF THE STUDY AREA

Glen Valley Wastewater Treatment Plant is a 90 Ml/day capacity facility comprising the old and new plants of capacity 40 Ml/day and 50 Ml/day respectively which serves Gaborone municipality and the surrounding settlements. Gaborone is the capital city of Botswana. The treatment plant which started operation in 2009 was designed to treat incoming streams of both domestic and industrial wastewater as well as substantial amount of evacuated wastes pit latrines around the city. Glen Valley is now run by Water Utility Corporation. It is located at Broudhurst in the northeastern part of Gaborone. Although Gaborone is not a heavily industrialized city, it accounts for major industries such as breweries, abattoirs, paper and pulp, pharmaceutical, paints and chemical industries which discharge their wastewater into the sewer networks. The wastewater undergoes both primary and secondary (biological) treatment where both primary sludge and secondary sludge are formed. The treated sludge is stored in piles for the use of local farmers and individuals as manure for agriculture purpose. Typical treatment processes employed at Glen Valley treatment plant includes primary settlement, secondary settlement, aerobic digestion and anaerobic digestion.

III. EXPERIMENTAL PROGRAMME

A. *Materials*

Treated sludge was collected in several polythene bags from Glen Valley Treatment Plant in Gaborone, Botswana. The physical and biological properties of the raw treated sludge were evaluated. The sludge was thereafter sun-dried for 24 hours, premixed, and successively quartered to obtain uniform representative samples. The samples were later incinerated in an electrical furnace in the Structural Engineering Laboratory of University of Botswana at a rate of 10°C/ min up to a maximum temperature of 800°C and were maintained at this temperature for 2 hours to form ash. It was later allowed to cool at room temperature in a vacuum desiccator to exclude absorbed water. The sludge ash was ground in a miller and sieved through 150 µm prior to analysis. The sludge ash was also analyzed for the physical and chemical properties as well as the mineralogical composition.

B. *Analyses of Sludge Ash Samples*

The specific gravity of sludge ash was determined by pycnometer. The particle size distribution was analyzed by laser diffraction over the size range 0.4–900 µm using Beckman Coulter LS-100. The specific surface area and pore size distribution of sludge ash was determined by a single port Gas Sorption Analyzer Coulter Omnisorp 100 using the Brunauer–Emmett–Teller (BET) test method. The pH was determined by preparing a 1:5 sludge ash to liquid ratio suspension using deionized water. The mixture was shaken for 5 min and left for 3 hours to equilibrate before measuring the pH in accordance with BS 7755 [17].

The chemical composition of the sludge ash was determined by X-ray fluorescence (XRF) using dispersive energy spectrophotometer. The elemental oxide contents in the sludge especially the silicon oxide (SiO_2) or silica present was a principal criterion for a good pozzolan. Loss on ignition (LOI), which is a measure of percentage of organic content (carbon) in the material, was determined by oven drying 2–3 g of material at 105°C to constant mass before calcining at 800°C for 2 hours, cooling and re-weighing. The loss in weight is expressed as a percentage of the original sample. Mineral composition of the sludge ash samples was determined by random X-ray diffraction (XRD) procedure at the Department of Geology of University of Botswana in line with ASTM C204.

IV. RESULTS AND DISCUSSION

A. *Physical Properties*

The texture of sun-dried sludge was rough, while the smoothness of the sieved sludge ash was comparable to cement as shown in Fig. 1. The colour of the sundried sludge was deep gray and changed to reddish brown after incineration to a temperature of 800°C in 2 hours. The loose bulk density of sludge ash was 810 kg/m^3. The pH of the sludge ash was 7.1, the specific gravity was 2.45 g/cm^3 and the BET surface area was 6.7 m^2/g. The results agreed with the findings of Donatello *et al*. [18]. It is obvious from the particle size distribution of the sludge ash in Fig. 2 that over 60% of the material was finer than 150 µm.

B. *Biological Parameters*

The samples were socked with distilled water shaken. From there the 428 ml supernatant was used for testing as per standards. Then 3 drops of the nitrification inhibitor was added to the sample for nitrification and 3 pellets of sodium hydroxide were added to stopper for gas absorption. It was observed that raw sludge had dissolved oxygen while SSA had none. This is because there were some suspended particles that trapped in oxygen within raw sludge whereas sludge ash was more soluble. Hence, there was no trapped air within the sludge ash suspension. The biochemical oxygen demand (BOD_5) after 5 days at 20°C, dissolved oxygen (DO) and total dissolved solids (TDS) of raw sewage sludge were 353 mg/l, 0.3 mg/l and 0.07 mg/l, respectively. The conductivity of the sample was 0.10 μs and the mean temperature of the sludge was 25.7°C.

Sun-dried raw sludge

Sludge ash ≤150 μm

Fig 1. The texture of raw sludge and sludge ash ≤150 μm sludge

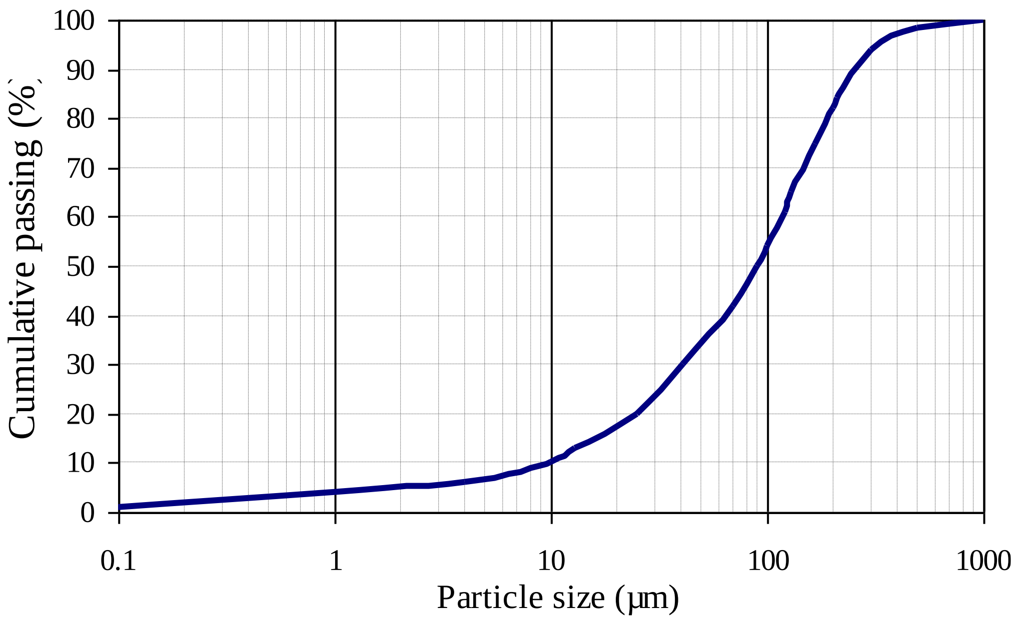

Fig. 2. Cumulative particle size distribution of sludge ash from Glenn Valley Plant

However, sludge ash had a slightly higher temperature than the raw sludge when some quantity of water was added, because the chemical reactions of oxides and heavy compounds produced heat in the sludge ash.

C. Chemical Composition and Mineralogy of Sludge Ash

The chemical constituents of the sludge ash produced from the Glen Valley wastewater treatment plant as analyzed by XRF is tabulated in Table 1. It can be observed silica and alumina contents accounted for 50.7% of the constituents of the sludge ash. The sum of SiO_2, Al_2O_3 and Fe_2O_3 was 64%. Also, high content of Fe_2O_3 (> 10%), which is a reactive oxides as the previous two, qualified the ash as an active mineral addition in partial replacement of cement in concretes and mortars. With the CaO content (> 10%), the ash is expected to behave as an inert mineral residue. The 8.5% content of phosphorus, indicated by P_2O_5, explained why farmers collect the treated sludge as a phosphate fertilizer for agricultural purposes. The combination of reactive oxides, inert mineral and phosphate oxide in a significant level is an indication of varieties sources of waste discharged into Glen Valley treatment plant. The low value of LOI (< 10%) shows that organic content in the sludge is relatively low, thereby enhancing the binding properties of the sludge ash when mixed with cement.

TABLE 1: CHEMICAL COMPOSITION OF SLUDGE ASH

Constituents	% by weight of dry sample (average of three samples)	Constituents	% by weight of dry sample (average of three samples)
SiO_2	40.3	K_2O	0.9
Al_2O_3	10.4	Na_2O	2.9
Fe_2O_3	13.3	MnO	0.1
CaO	13.1	TiO_2	0.5
MgO	1.7	SO_3	3.6
P_2O_5	8.5	Cl	0.1
LOI	4.6		

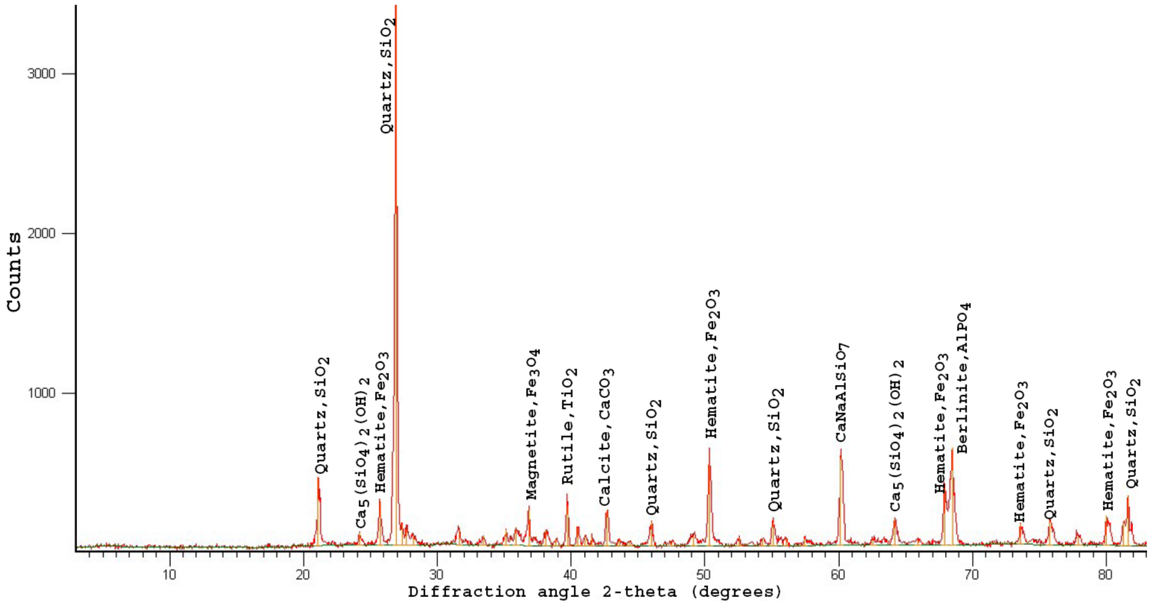

Fig. 3. X-ray powder diffractogram of sludge ash

The XRD analysis shown in Fig. 3 revealed mainly amorphous phase with some peaks of crystalline phases of magnetite, magnesioferrite and different calcium-containing mineralogical compounds due to the presence of calcium oxide contents.

V. CONCLUSIONS

The utilization of blended cement is mounting rapidly in construction industry due to the considerations of environmental protection, waste management, sustainable development and cost saving without compromising strength and durability. The raw wastewaters discharged into Glen Valley treatment plant were essentially domestic/municipal and industrial wastewaters. The physical and biological properties of the sludge produced at the treatment plant explained why farmers collect the sludge as manure for agricultural purposes. The physical, chemical and mineralogical properties of the sludge incinerated at 800°C for two hours revealed its suitability as an active mineral materials in partial replacement for cement in concretes and mortars. The bulk density, pH, specific gravity and the surface area of the sludge ash met the requirements for cementitious materials. The chemical composition of the sludge ash conducted by XRF analysis showed that the ash is composed of reactive oxides which are an active mineral addition in partial replacement of cement. The XRD analysis of the sludge ash revealed mainly amorphous phase with some peaks of crystalline phases of magnetite, magnesioferrite and different calcium-containing mineralogical compounds due to the presence of calcium oxide contents. The findings showed the potentials of the sludge ash in partial replacement of cement in concretes and mortars.

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REFERENCES

[1] F. Baeza-Brotons, P. Garcés, J. Payá, and J.M. Saval, Portland cement systems with addition of sewage sludge ash. Application in concretes for the manufacture of blocks. *Journal of Cleaner Production*. **82**:112-124, 2014.

[2] E. Benhelal, G. Zahedi, E. Shamsaei, and A. Bahadori, Global strategies and potentials to curb CO_2 emissions in cement industry. *Journal of Cleaner Production*. **51**:142-161, 2013.

[3] T.O. Adewuyi and A.A. Umoh, Influence of bamboo leaf ash blended cement on the engineering properties of lateritic bricks. *Journal of Engineering and Technology*, 7(1): 18 – 29, 2016.

[4] P. Chindaprasirt, and S. Rukzon, Strength and chloride resistance of the blended Portland cement mortar containing rice husk ash and ground river sand. *Materials and Structures*, 48:3771–3777, 2015.

[5] D. Ravina, and P.K. Mehta, Properties of fresh concrete containing large amounts of fly ash, Cement & Concrete Research, **16**(2): 227–238, 1986.

[6] M.C. Limbachiya, Bulk engineering and durability properties of washed glass sand concrete, *Construction and Building Materials,* 23(9): 1078–1083, 2009.

[7] T.D. Dyer, and R.K. Dhir, Chemical reactions of glass cullet used as cement component. *Journal of Materials in Civil Engineering,* 13(6): 412–417, 2001.

[8] Z.P. Bazant, G. Zi, and C. Meyer, Fracture mechanics of ASR in concretes with waste glass particles of different sizes. *Journal of Engineering Mechanics.* (126): 226–232, 2000.

[9] M. Etxeberria, E. Vázquez, A. Marí, and M. Barra, Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete, *Cement and Concrete Research*, **37**(5): 735–742, 2007.

[10] O.S. Olafusi, A.P. Adewuyi, A.I. Otunla, and A.O. Babalola, Evaluation of Fresh and Hardened Properties of Self-Compacting Concrete. *Open Journal of Civil Engineering*, 5: 1-7, 2015.

[11] A.U. Elinwa, and A.M. Mamuda, Sawdust ash as powder material for self-compacting concrete containing naphthalene sulfonate. *Advances in Civil Engineering*, 129276: 1-8, 2014.

[12] A.P. Adewuyi, and T. Adegoke, Exploratory study of periwinkle shells as coarse aggregates in concrete works, *ARPN Journal of Engineering and Applied Sciences*, 3(6): 1-5, 2008.

[13] A.P. Adewuyi, and B.F. Ola, Application of waterworks sludge as partial replacement for cement in concrete production, *International Journal of Biological and Physical Sciences*, 10(1): 123-130, 2005.

[14] M. Chen, D. Blanc, M. Gautier, J. Mehu, and R. Gourdon, Environmental and technical assessments of the potential utilization of sewage sludge ashes (SSAs) as secondary raw materials in construction. *Waste Management*, **33**(5): 1268-1275, 2013.

[15] W. Kępys, R. Pomykała, and J. Pietrzyk, Properties of fly ash from thermal conversion of municipal sewage sludge. *Journal of the Polish Mineral Engineering Society*. 1: 11-18, 2013.

[16] O.A. Johnson, M. Napiah, and I. Kamaruddin, Potential uses of waste sludge in construction Industry: a review. *Research Journal of Applied Sciences, Engineering and Technology*, **8**(4): 565-570, 2014.

[17] . BS 7755 (1995) Soil quality- Part 3: Chemical methods. Determination of pH - Section 3.2, London, British Standards Institution.

[18] S. Donatello, M. Tyrer, and C.R. Cheeseman, Comparison of test methods to assess pozzolanic activity. *Cement & Concrete Composites*, 32: 121–127, 2010.